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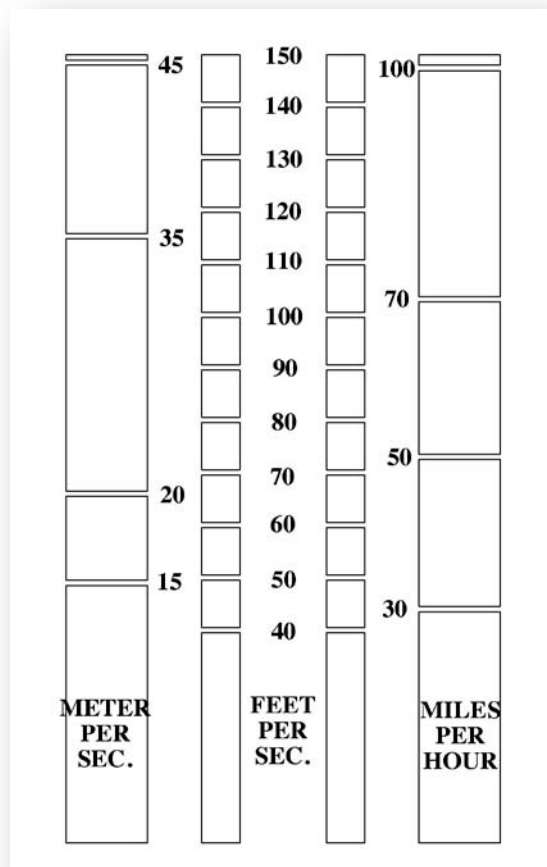
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ROCK STRIKE TESTING OF TRANSPARENT ARMOR NLE-01

David N. Hansen, Ph.D.
Ashley Wagner

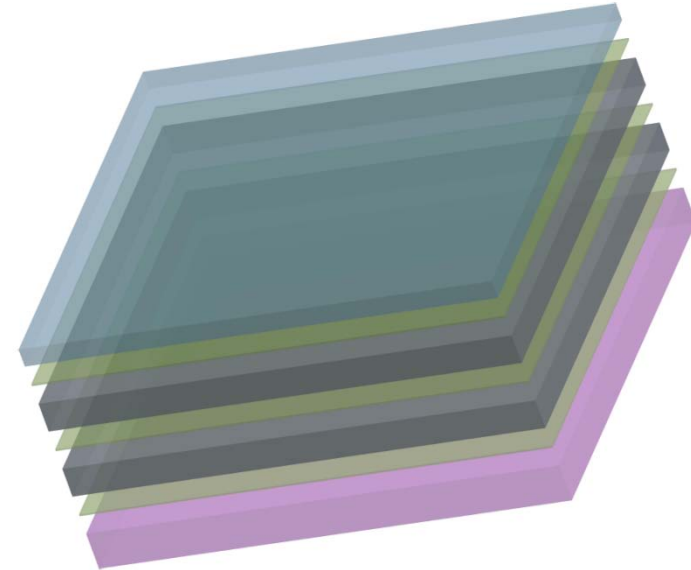
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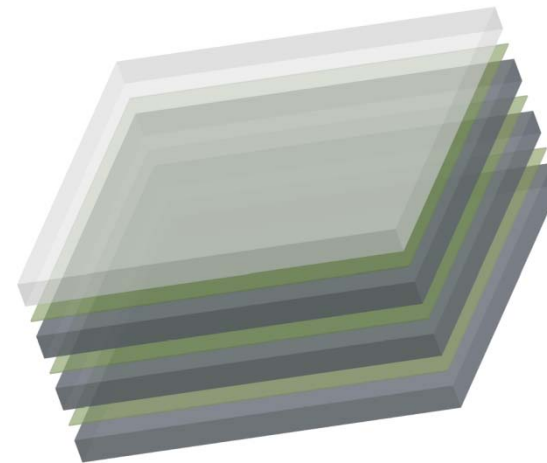
6 X 6 ALL GLASS

1	0.236"	Annealed water white (low iron) clear glass
2	0.025"	Urethane Interlayer Huntsman PE 399
3	0.388"	Annealed water white clear glass
4	0.025"	Urethane Interlayer Huntsman PE 399
5	0.388"	Annealed water white clear glass
6	0.025"	Urethane Interlayer Huntsman PE 399
7	0.490"	Annealed water white clear glass



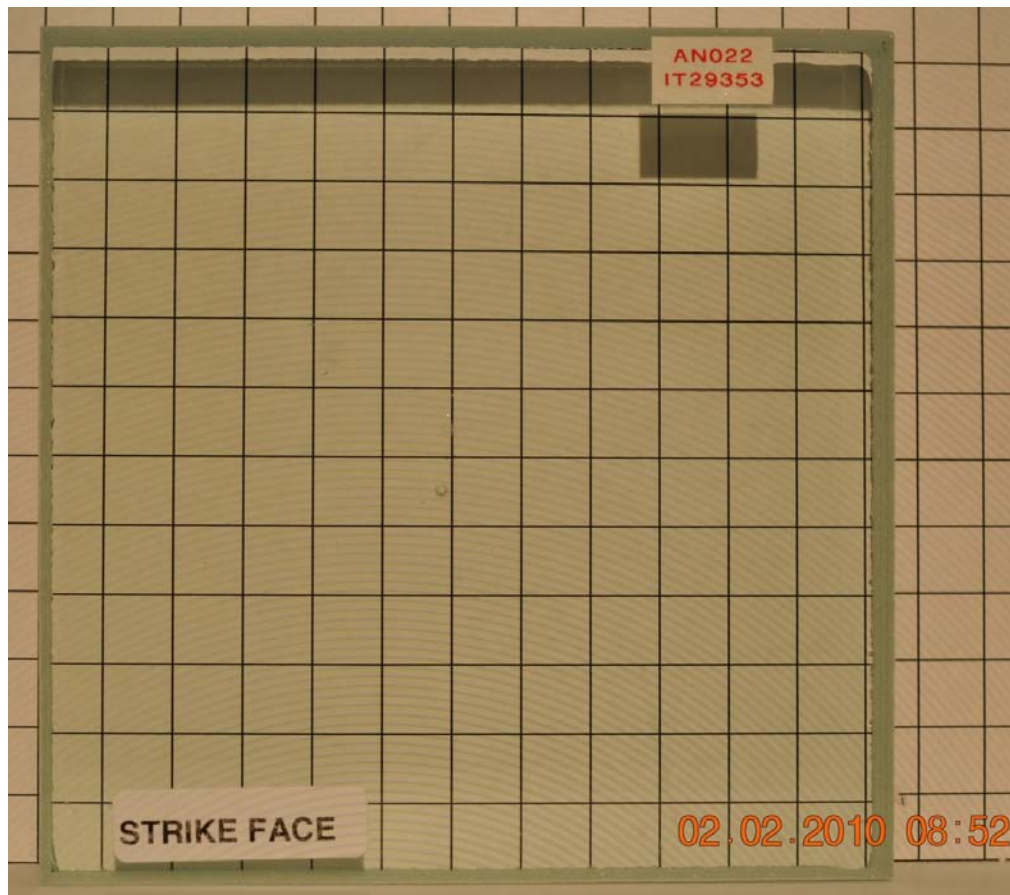
4 X 4 GLASS CERAMIC

1	0.388"	Glass ceramic
2	0.025"	Urethane Interlayer Huntsman PE 399
3	0.388"	Annealed water white clear glass
4	0.025"	Urethane Interlayer Huntsman PE 399
5	0.388"	Annealed water white clear glass
6	0.025"	Urethane Interlayer Huntsman PE 399
7	0.388"	Annealed water white clear glass



DEVIATION FROM GOAL SPEED IN f/s.

Speed Group	Ann. Gl. Deviation 6mm	Ann. Gl. Deviation 12mm	Gl. Ceram Deviation 6mm	Gl. Ceram Deviation 12mm
40	2.8	4.7	1.0	4.7
50	-1.6	3.9	-2.3	3.5
60	1.8	2.4	1.8	1.7
70	1.2	-1.0	1.1	-0.5
80	4.5	-1.7	1.7	-1.7
90	-1.2	1.8	-1.3	0.5
100	-0.2	-1.1	-0.7	0.7
110	0.7	3.4	0.9	-2.2
120	2.6	0.0	2.0	3.1
130	1.2	2.5	1.5	-1.4
140	2.7	0.5	3.1	-0.7
150	1.3	2.8	0.2	3.8



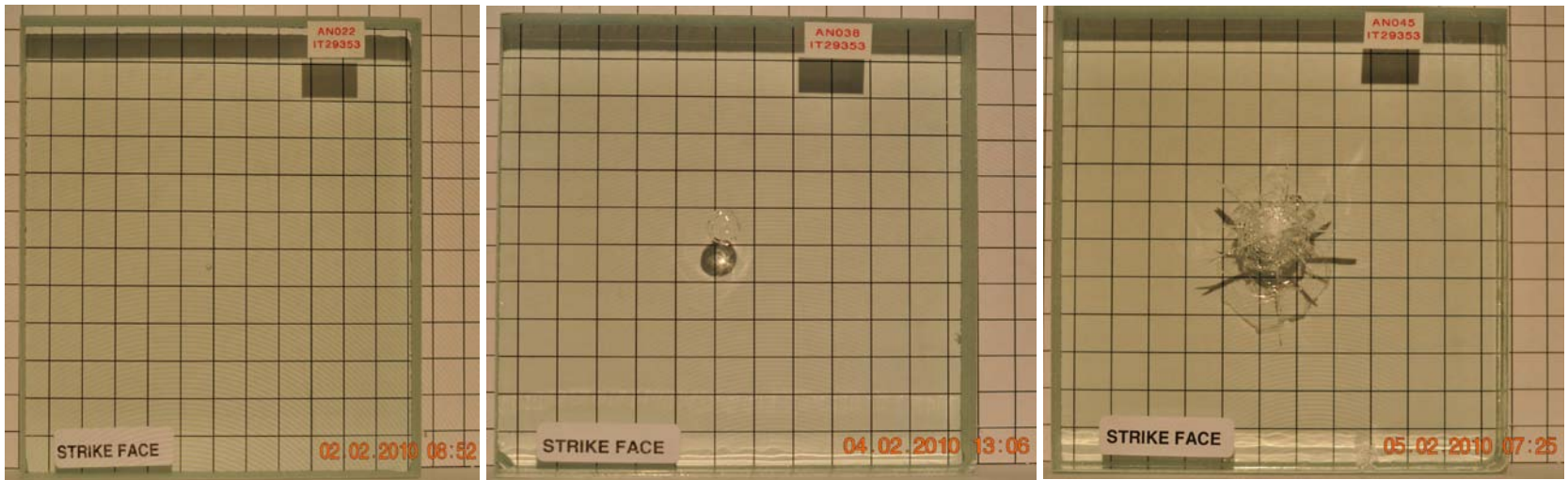
AN022 12mm BALL AT 135 f/s, RANKED 1



AN038 12mm BALL AT 129 f/s, RANKED 3



AN045 12mm BALL AT 133 f/s, RANKED 5



VARIABILITY OF CRACK RESPONSE WHERE ALL OF THE STRIKING PROJECTILES WERE VERY SIMILAR AND THE STRIKING SPEEDS WERE WITHIN 3 f/s OF 132 f/s.

THERMAL SHOCK TESTS (ATPD)

18 HOURS AT -30 C

5 MINUTES OR LESS, TRANSFER
TIME

18 HOURS AT +60 C

5 MINUTES OR LESS, TRANSFER
BACK TO START AND REPEAT 4X

THERMAL SHOCK OBSERVATIONS

CRACK EXTENSIONS

MEASURE CRACKS BEFORE AND AFTER

DELAMINATION

DYE PENETRANT

CRACK EXTENSION



THERMAL CYCLING DELAMINATION

DYE PENETRANT EXAMINATION
WAS SCRAPPED

VISUAL EXAMINATION NEVER
HINTED AT DELAMINATION
OCCURRING

ALL "AFTER" CYCLING
PHOTOGRAPHS WERE EXAMINED
AND RANKED

CONTRACTOR COUNT OF UNDAMAGED COUPONS

SPEED	40	50	60	70
AN-6	6	4	6	3
AN-12	7	0	12	1

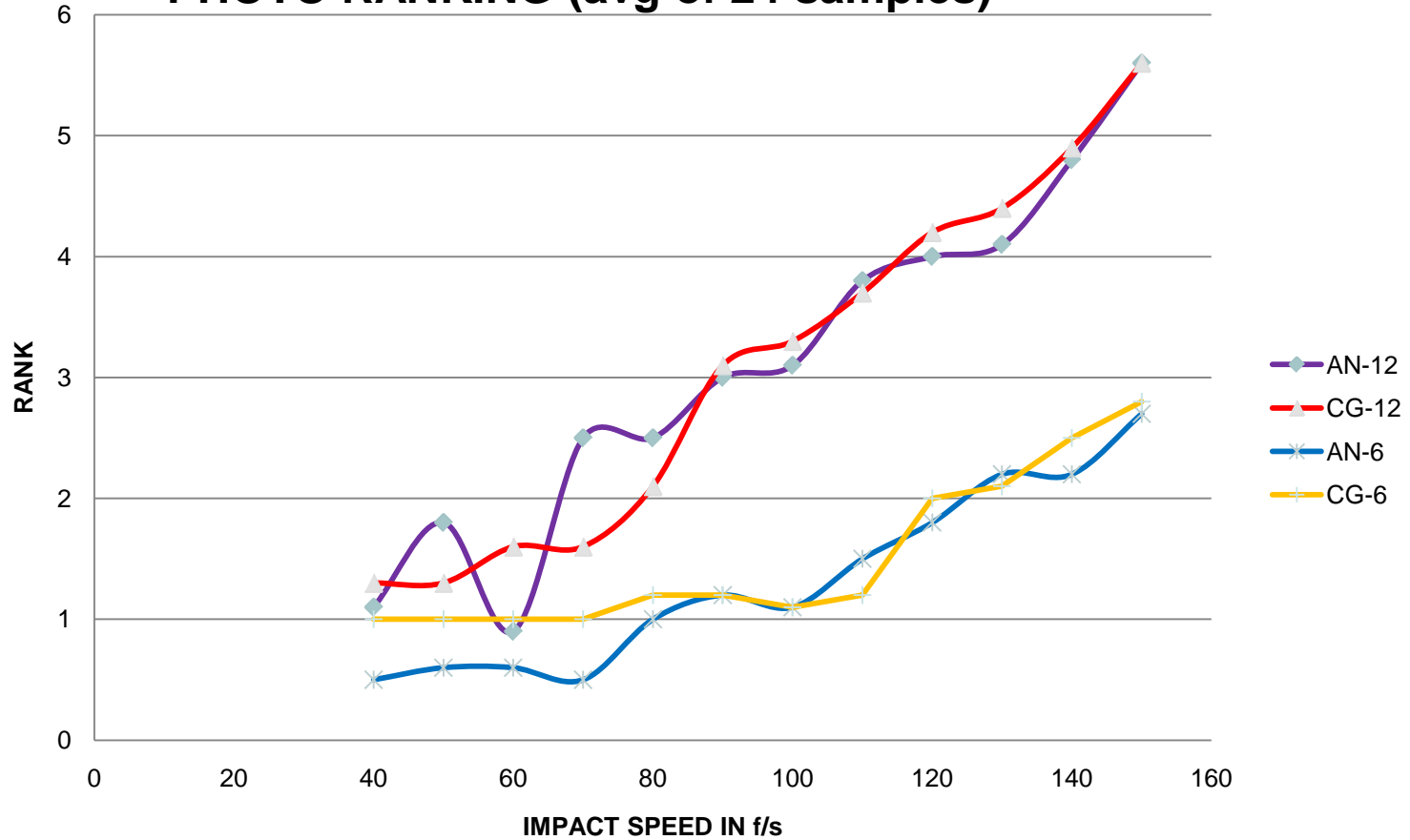
RANKING OF IMPACTS

130 fps, 12 mm ball		
Target Number	Small Circularly Cracked	Radially Cracked
AN022	X	
AN038	X	
AN045		X
AN090		X
AN091	X	
AN092	X	
AN093	X	
AN094		X
AN095	X	
AN096		X
AN104		X
AN105		X
AN106	X	
AN107		X
AN108		X
AN109		X
AN110		X
AN115		X
AN116		X
AN117		X
AN119		X
AN120	X	
AN121		X
AN122		X
	8	16

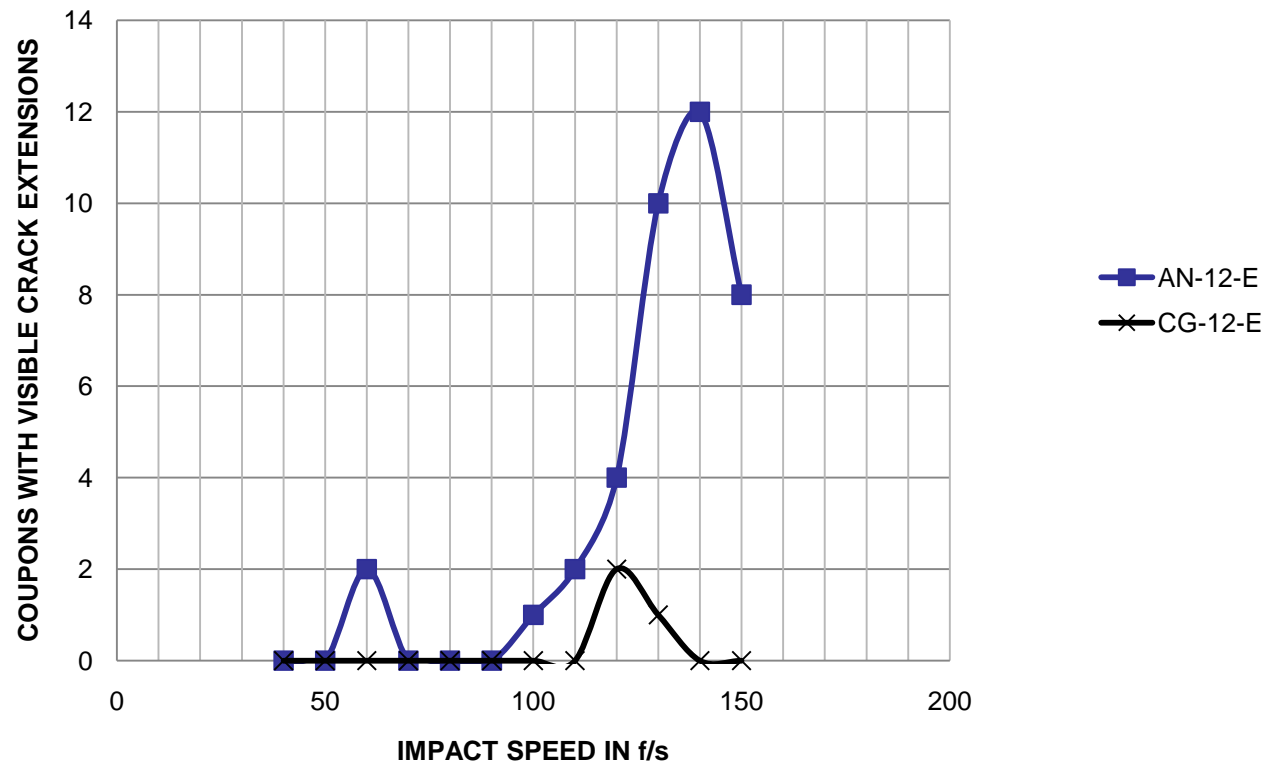
Damage Descriptions and Rank			Attributes
Light Crush or Ring with no Crush	CRS	1	Often only seen as a shadow and less than quarter inch diameter.
Small Circular Crack	SCC	2	About quarter inch diameter with or without small radial cracks
Circular Crack	NCC	3	Greater than about 3/8" and less than 1 1/4" diameter, some small radial cracks may be present
Large Circular Crack with or without Crush	LCC	4	Greater than about 1" with no radial cracks greater than circular crack diameter
Large Circular Crack with Radial Cracks	LCR	5	Radial cracks not much larger than largest circular crack.
Large Circular, Radial, Crush, Failures	LCRC	6	Numerous radial cracks not much larger than about 150% of largest circular crack and crush apparent.
Radial Cracks to Edge	RCE	7	Three radial cracks extending 2 or more inches or to the edge of the coupon.

MODIFICATION 2+

PHOTO RANKING (avg of 24 samples)



THERMAL SHOCK INDUCED CRACK EXTENSIONS



SUMMARY

Visual examination of event photographs can yield expected behavior plots.

An impact with a half inch bearing at about 100 f/s could be the basis of a test.

The 100 f/s test could indicate the variability
A ranking of about 3 would be a good basis for a rock strike test.